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Physiology focuses on mechanisms of action. 2
Structure and function are inseparable. 2

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The tissue level: Tissues are groups of cells of similar specialization. 5
The organ level: An organ is a unit made up of several tissue types. 7
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Body systems maintain homeostasis, a dynamic steady state in the internal environment. 8

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Factors other than the partial pressure gradient influence the rate of gas transfer. 468

Gas exchange across the systemic capillaries also occurs down partial pressure gradients. 471

13.4 Gas Transport 471

Most O_2 in the blood is transported bound to hemoglobin. 471
The P_{O_2} is the primary factor determining the percent hemoglobin saturation. 472
Hemoglobin promotes the net transfer of O_2 at both the alveolar and the tissue levels. 473
Factors at the tissue level promote unloading of O_2 from hemoglobin. 474
Hemoglobin has a much higher affinity for carbon monoxide than for O_2 . 475
Most CO_2 is transported in the blood as bicarbonate. 476
Various respiratory states are characterized by abnormal blood-gas levels. 477

13.5 Control of Respiration 479

Respiratory centers in the brain stem establish a rhythmic breathing pattern. 479

Concepts, Challenges, and Controversies: Effects of Heights and Depths on the Body 480

Ventilation magnitude is adjusted in response to three chemical factors: P_{O_2} , P_{CO_2} , and H^+ . 481
Decreased arterial P_{O_2} increases ventilation only as an emergency mechanism. 482
 CO_2 -generated H^+ in the brain is normally the main regulator of ventilation. 483
Adjustments in ventilation in response to changes in arterial H^+ are important in acid-base balance. 484
Exercise profoundly increases ventilation by unclear mechanisms. 485
Ventilation can be influenced by factors unrelated to the need for gas exchange. 486
During apnea, a person “forgets to breathe”; during dyspnea, a person feels “short of breath.” 486

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14.1 Kidneys: Functions, Anatomy, and Basic Processes 492

The kidneys perform a variety of functions aimed at maintaining homeostasis. 492
The kidneys form urine; the rest of the urinary system carries it to the outside. 492
The nephron is the functional unit of the kidney. 493
The three basic renal processes are glomerular filtration, tubular reabsorption, and tubular secretion. 496

14.2 Glomerular Filtration 498

The glomerular membrane is considerably more permeable than capillaries elsewhere. 498

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Glomerular capillary blood pressure is the major force that causes glomerular filtration. 499
Changes in GFR result mainly from changes in glomerular capillary blood pressure. 500
The GFR can be influenced by changes in the filtration coefficient. 504
The kidneys normally receive 20% to 25% of the cardiac output. 504

14.3 Tubular Reabsorption 505

Tubular reabsorption is tremendous, highly selective, and variable. 505
Tubular reabsorption involves transepithelial transport. 505
 Na^+ reabsorption depends on the Na^+-K^+ ATPase pump in the basolateral membrane. 506
Aldosterone stimulates Na^+ reabsorption in the distal and collecting tubules. 507
The natriuretic peptides inhibit Na^+ reabsorption. 509
Glucose and amino acids are reabsorbed by Na^+ -dependent secondary active transport. 510
In general, actively reabsorbed substances exhibit a tubular maximum. 510
Glucose is an actively reabsorbed substance not regulated by the kidneys. 511
Phosphate is an actively reabsorbed substance regulated by the kidneys. 512
Active Na^+ reabsorption is responsible for passive reabsorption of Cl^- , H_2O , and urea. 512
In general, unwanted waste products are not reabsorbed. 514

14.4 Tubular Secretion 514

Hydrogen ion secretion is important in acid-base balance. 514
Potassium ion secretion is controlled by aldosterone. 514
Organic anion and cation secretion hastens elimination of foreign compounds. 516

14.5 Urine Excretion and Plasma Clearance 517

Plasma clearance is the volume of plasma cleared of a particular substance per minute. 517
Clearance rates for inulin and PAH can be used to determine the filtration fraction. 520
The kidneys can excrete urine of varying concentrations depending on body needs. 520
Long Henle’s loops establish the vertical osmotic gradient by countercurrent multiplication. 521
Vasopressin controls variable H_2O reabsorption in the final tubular segments. 523
The vasa recta preserve the vertical osmotic gradient by countercurrent exchange. 526
Water reabsorption is only partially linked to solute reabsorption. 527
Renal failure has wide-ranging consequences. 527
Urine is temporarily stored in the bladder, from which it is emptied by micturition. 528

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15.1 Balance Concept 536

The internal pool of a substance is the amount of that substance in the ECF. 536

To maintain stable balance of an ECF constituent, its input must equal its output. 536

15.2 Fluid Balance 537

Body water is distributed between the ICF and the ECF compartments. 537

Plasma and interstitial fluid are similar in composition, but ECF and ICF differ markedly. 538

Fluid balance is maintained by regulating ECF volume and osmolarity. 538

Control of ECF volume is important in the long-term regulation of blood pressure. 539

Control of salt balance is primarily important in regulating ECF volume. 539

Controlling ECF osmolarity prevents changes in ICF volume. 540

During ECF hypertonicity, cells shrink as H_2O leaves them. 541

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During ECF hypotonicity, the cells swell as H_2O enters them. 543

No water moves into or out of cells during an ECF isotonic fluid gain or loss. 543

Vasopressin control of free H_2O balance is important in regulating ECF osmolarity. 543

Vasopressin secretion and thirst are largely triggered simultaneously. 545

15.3 Acid–Base Balance 547

Acids liberate free hydrogen ions, whereas bases accept them. 547

The pH designation is used to express $[H^+]$. 548

Fluctuations in $[H^+]$ alter nerve, enzyme, and K^+ activity. 549

Hydrogen ions are continually added to the body fluids as a result of metabolic activities. 549

Chemical buffer systems minimize changes in pH by binding with or yielding free H^+ . 550

The H_2CO_3/HCO_3^- buffer pair is the primary ECF buffer for noncarbonic acids. 551

The protein buffer system is primarily important intracellularly. 552

The hemoglobin buffer system buffers H^+ generated from CO_2 . 552

The phosphate buffer system is an important urinary buffer. 552

Chemical buffer systems act as the first line of defense against changes in $[H^+]$. 553

The respiratory system regulates $[H^+]$ by controlling the rate of CO_2 removal. 553

The respiratory system serves as the second line of defense against changes in $[H^+]$. 553

The kidneys adjust their rate of H^+ excretion by varying the extent of H^+ secretion. 554

The kidneys conserve or excrete HCO_3^- depending on the plasma $[H^+]$. 555

The kidneys secrete ammonia during acidosis to buffer secreted H^+ . 558

The kidneys are a powerful third line of defense against changes in $[H^+]$. 558

Acid–base imbalances can arise from either respiratory or metabolic disturbances. 558

Respiratory acidosis arises from an increase in $[CO_2]$. 559

Respiratory alkalosis arises from a decrease in $[CO_2]$. 559

Metabolic acidosis is associated with a fall in $[HCO_3^-]$. 561

Metabolic alkalosis is associated with an elevation in $[HCO_3^-]$. 561

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16.1 General Aspects of Digestion 566

The digestive system performs four basic digestive processes. 566

The digestive tract and accessory digestive organs make up the digestive system. 569

The digestive tract wall has four layers. 570

Regulation of digestive function is complex and synergistic. 571

Receptor activation alters digestive activity through neural and hormonal pathways. 572

16.2 Mouth 573

The oral cavity is the entrance to the digestive tract. 573

The teeth mechanically break down food. 574

Saliva begins carbohydrate digestion and helps swallowing, speech, taste, and oral health. 574

Salivary secretion is continuous and can be reflexly increased. 575

Digestion in the mouth is minimal; no absorption of nutrients occurs. 575

16.3 Pharynx and Esophagus 575

Swallowing is a sequentially programmed all-or-none reflex. 576
During swallowing, food is prevented from entering the wrong passageways. 576
The pharyngoesophageal sphincter prevents air from entering the digestive tract. 576
Peristaltic waves push food through the esophagus. 576
The gastroesophageal sphincter prevents reflux of gastric contents. 578
Esophageal secretion is entirely protective. 578

16.4 Stomach 578

The stomach stores food and begins protein digestion. 578
Gastric filling involves receptive relaxation. 579
Gastric storage takes place in the body of the stomach. 579
Gastric mixing takes place in the antrum of the stomach. 579
Gastric emptying is largely controlled by factors in the duodenum. 579

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Emotions can influence gastric motility. 582
The stomach does not actively participate in vomiting. 582
Gastric digestive juice is secreted by glands located at the base of gastric pits. 582
Hydrochloric acid is secreted by parietal cells and activates pepsinogen. 584
Pepsinogen is activated to pepsin, which begins protein digestion. 585
Mucus is protective. 585
Intrinsic factor is essential for absorption of vitamin B₁₂. 585
Multiple regulatory pathways influence the parietal and chief cells. 585
Control of gastric secretion involves three phases. 586
Gastric secretion gradually decreases as food empties from the stomach into the intestine. 587
The gastric mucosal barrier protects the stomach lining from gastric secretions. 587
Carbohydrate digestion continues in the body of the stomach; protein digestion begins in the antrum. 588
The stomach absorbs alcohol and aspirin but no food. 588

16.5 Pancreatic and Biliary Secretions 588

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The pancreas is a mixture of exocrine and endocrine tissue. 590
The exocrine pancreas secretes digestive enzymes and an alkaline fluid. 590
Pancreatic exocrine secretion is regulated by secretin and CCK. 592

The liver performs various important functions, including bile production. 593

Bile is continuously secreted by the liver and is diverted to the gallbladder between meals. 595

Bile salts are recycled through the enterohepatic circulation. 595

Bile salts aid fat digestion and absorption. 595

Bile salts stimulate bile secretion; CCK promotes gallbladder emptying. 597

Bilirubin is a waste product excreted in the bile. 597

Hepatitis and cirrhosis are the most common liver disorders. 597

16.6 Small Intestine 598

Segmentation contractions mix and slowly propel the chyme. 598

The migrating motility complex sweeps the intestine clean between meals. 599

The ileocecal juncture prevents contamination of the small intestine by colonic bacteria. 599

Small-intestine secretions do not contain any digestive enzymes. 599

The small-intestine enzymes complete digestion within the brush-border membrane. 599

The small intestine is remarkably well adapted for its primary role in absorption. 600

The mucosal lining experiences rapid turnover. 602

Energy-dependent Na⁺ absorption drives passive H₂O absorption. 603

Digested carbohydrates and proteins are both absorbed by secondary active transport and enter the blood. 603

Digested fat is absorbed passively and enters the lymph. 605

Vitamin absorption is largely passive. 605

Iron and calcium absorption is regulated. 605

Most absorbed nutrients immediately pass through the liver for processing. 609

Extensive absorption by the small intestine keeps pace with secretion. 609

Biochemical balance among the stomach, pancreas, and small intestine is normally maintained. 609

Diarrhea results in loss of fluid and electrolytes. 610

16.7 Large Intestine 610

The large intestine is primarily a drying and storage organ. 610

Concepts, Challenges, and Controversies: Oral Rehydration Therapy: Sipping a Simple Solution Saves Lives 611

Haustral contractions slowly shuffle the colonic contents back and forth. 611

Mass movements propel feces long distances. 612

Feces are eliminated by the defecation reflex. 612

Constipation occurs when the feces become too dry. 612

Intestinal gases are absorbed or expelled. 612

Large-intestine secretion is entirely protective. 613

The colon contains myriad beneficial bacteria. 613

The large intestine absorbs salt and water, converting the luminal contents into feces. 614

Chapter 17 | Energy Balance and Temperature Regulation 618

17.1 Energy Balance 619

Most food energy is ultimately converted into heat in the body. 619

The metabolic rate is the rate of energy use. 619

Energy input must equal energy output to maintain a neutral energy balance. 621

Food intake is controlled primarily by the hypothalamus. 621

Obesity occurs when more kilocalories are consumed than are burned. 624

A Closer Look at Exercise Physiology: What the Scales Don't Tell You 625

People suffering from anorexia nervosa have a pathological fear of gaining weight. 627

17.2 Temperature Regulation 627

Internal core temperature is homeostatically maintained at 100°F (37.8°C). 627

Heat input must balance heat output to maintain a stable core temperature. 628

Heat exchange takes place by radiation, conduction, convection, and evaporation. 628

Sweating is a regulated evaporative heat-loss process. 630

The hypothalamus integrates a multitude of thermosensory inputs. 630

Shivering is the primary involuntary means of increasing heat production. 630

The magnitude of heat loss can be adjusted by varying the flow of blood through the skin. 632

The hypothalamus simultaneously coordinates heat-production and heat-loss mechanisms. 632

During a fever, the hypothalamic thermostat is "reset" at an elevated temperature. 633

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Hyperthermia can occur unrelated to infection. 634

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18.1 General Principles of Endocrinology 639

Hormones exert a variety of regulatory effects throughout the body. 640

The effective plasma concentration of a hormone is influenced by the hormone's secretion, peripheral conversion, transport, inactivation, and excretion. 640

The effective plasma concentration of a hormone is normally regulated by changes in the rate of its secretion. 641

Endocrine disorders result from hormone excess or deficiency or decreased target-cell responsiveness. 642

The responsiveness of a target cell can be varied by regulating the number of hormone-specific receptors. 643

18.2 Hypothalamus and Pituitary 646

The pituitary gland consists of anterior and posterior lobes. 646

The hypothalamus and posterior pituitary act as a unit to secrete vasopressin and oxytocin. 646

Most anterior pituitary hormones are tropic. 647

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Hypothalamic releasing and inhibiting hormones help regulate anterior pituitary hormone secretion. 648

Target-gland hormones inhibit hypothalamic and anterior pituitary hormone secretion via negative feedback. 651

18.3 Endocrine Control of Growth 652

Growth depends on GH but is influenced by other factors. 652

GH is essential for growth, but it also directly exerts metabolic effects not related to growth. 653

GH mostly exerts its growth-promoting effects indirectly by stimulating insulin-like growth factors. 653

GH, through IGF-I, promotes growth of soft tissues by stimulating hypertrophy and hyperplasia. 654

Bone grows in thickness and in length by different mechanisms, both stimulated by GH. 654

GH secretion is regulated by two hypophysiotropic hormones. 656

Abnormal GH secretion results in aberrant growth patterns. 657

Concepts, Challenges, and Controversies: Growth and Youth in a Bottle? 658

Other hormones besides growth hormone are essential for normal growth. 658

18.4 Pineal Gland and Circadian Rhythms 660

The suprachiasmatic nucleus is the master biological clock. 660

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Melatonin helps keep the body's circadian rhythms in time with the light–dark cycle. 661

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19.1 Thyroid Gland 666

The major cells that secrete thyroid hormone are organized into colloid-filled follicles. 666

Thyroid hormone is synthesized and stored on the thyroglobulin molecule. 666

To secrete thyroid hormone, the follicular cells phagocytize thyroglobulin-laden colloid. 668

Thyroid hormone increases the basal metabolic rate and exerts other effects. 668

Thyroid hormone is regulated by the hypothalamus–pituitary–thyroid axis. 669

Abnormalities of thyroid function include both hypothyroidism and hyperthyroidism. 669

A goiter develops when the thyroid gland is overstimulated. 671

19.2 Adrenal Glands 672

Each adrenal gland consists of a steroid-secreting cortex and a catecholamine-secreting medulla. 672

The adrenal cortex secretes mineralocorticoids, glucocorticoids, and sex hormones. 672

The major effects of mineralocorticoids are on Na^+ and K^+ balance and blood pressure homeostasis. 674

Glucocorticoids exert metabolic effects and play a key role in adaptation to stress. 674

Cortisol secretion is regulated by the hypothalamus–pituitary–adrenal cortex axis. 675

The adrenal cortex secretes both male and female sex hormones in both sexes. 676

The adrenal cortex may secrete too much or too little of any of its hormones. 676

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The adrenal medulla consists of modified sympathetic postganglionic neurons. 681

Epinephrine and norepinephrine vary in their affinities for different receptor types. 681

Epinephrine reinforces the sympathetic nervous system and exerts metabolic effects. 681

Epinephrine is released only on sympathetic stimulation of the adrenal medulla. 682

19.3 Integrated Stress Response 682

The stress response is a generalized pattern of reactions to any situation that threatens homeostasis. 683

The multifaceted stress response is coordinated by the hypothalamus. 683

Activation of the stress response by chronic psychosocial stressors may be harmful. 684

19.4 Endocrine Pancreas and Control of Fuel Metabolism 685

Fuel metabolism includes anabolism, catabolism, and interconversions among energy-rich organic molecules. 685

Because food intake is intermittent, nutrients must be stored for use between meals. 687

The brain must be continuously supplied with glucose. 687

Metabolic fuels are stored during the absorptive state and mobilized during the postabsorptive state. 688

Lesser energy sources are tapped as needed. 689

The pancreatic hormones, insulin and glucagon, are most important in regulating fuel metabolism. 689

Insulin lowers blood glucose, fatty acid, and amino acid levels and promotes their storage. 690

The primary stimulus for increased insulin secretion is an increase in blood glucose. 692

The symptoms of diabetes mellitus are characteristic of an exaggerated postabsorptive state. 693

Concepts, Challenges, and Controversies: Diabetics and Insulin: Some Have It and Some Don't 696

Insulin excess causes brain-starving hypoglycemia. 698

Glucagon in general opposes the actions of insulin. 698

Glucagon secretion is increased during the postabsorptive state. 698

Insulin and glucagon work as a team to maintain blood glucose and fatty acid levels. 699

Glucagon excess can aggravate the hyperglycemia of diabetes mellitus. 699

Epinephrine, cortisol, and growth hormone also exert direct metabolic effects. 699

The hypothalamus plays a role in controlling glucose homeostasis. 701

19.5 Parathyroid Glands and Control of Calcium Metabolism 701

Plasma Ca^{2+} must be closely regulated to prevent changes in neuromuscular excitability. 701

Control of Ca^{2+} metabolism includes regulation of both Ca^{2+} homeostasis and Ca^{2+} balance. 702

Parathyroid hormone raises free plasma Ca^{2+} , a life-saving effect. 702

Bone continuously undergoes remodeling. 703

Mechanical stress favors bone deposition. 704

PTH raises plasma Ca^{2+} by withdrawing Ca^{2+} from the bone bank. 704

PTH's immediate effect is to promote transfer of Ca^{2+} from bone fluid into plasma. 704

PTH's chronic effect is to promote localized dissolution of bone to release Ca^{2+} into plasma. 705

A Closer Look at Exercise Physiology: Osteoporosis: The Bane of Brittle Bones 706

PTH acts on the kidneys to conserve Ca^{2+} and eliminate PO_4^{3-} . 706

PTH indirectly promotes absorption of Ca^{2+} and PO_4^{3-} by the intestine. 708

The primary regulator of PTH secretion is plasma concentration of free Ca^{2+} . 708

Calcitonin lowers plasma Ca^{2+} concentration but is not important in the normal control of Ca^{2+} metabolism. 708

Vitamin D is actually a hormone that increases Ca^{2+} absorption in the intestine. 709

Phosphate metabolism is controlled by the same mechanisms that regulate Ca^{2+} metabolism. 710

Disorders in Ca^{2+} metabolism may arise from abnormal levels of PTH or vitamin D. 712



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20.1 Uniqueness of the Reproductive System 716

Unique among body systems, the reproductive system does not contribute to homeostasis but plays other roles. 716

The reproductive system includes the gonads, reproductive tract, and accessory sex glands, all of which differ in males and females. 716

Reproductive cells each contain a half set of chromosomes. 718

Gametogenesis is accomplished by meiosis, resulting in genetically unique sperm and ova. 718

The sex of an individual is determined by the combination of sex chromosomes. 718

Sexual differentiation along male or female lines depends on the presence or absence of masculinizing determinants. 721

20.2 Male Reproductive Physiology 723

The scrotal location of the testes provides a cooler environment for spermatogenesis. 723

The testicular Leydig cells secrete masculinizing testosterone. 725

Spermatogenesis yields an abundance of highly specialized, mobile sperm. 726

Throughout their development, sperm remain intimately associated with Sertoli cells. 728

LH and FSH from the anterior pituitary control testosterone secretion and spermatogenesis. 729

GnRH activity increases at puberty. 730

The reproductive tract stores and concentrates sperm and increases their fertility. 730

The accessory sex glands contribute the bulk of the semen. 731

20.3 Sexual Intercourse between Males and Females 732

The male sex act is characterized by erection and ejaculation. 732

Erection is accomplished by penis vasocongestion. 732

Ejaculation includes emission and expulsion. 734

Orgasm and resolution complete the sexual response cycle. 734

Volume and sperm content of the ejaculate vary. 735

The female sexual cycle is similar to the male cycle. 735

Concepts, Challenges, and Controversies: Environmental "Estrogens": Bad News for the Reproductive System 736

20.4 Female Reproductive Physiology 736

Complex cycling characterizes female reproductive physiology. 736

The steps of gametogenesis are the same in both sexes, but the timing and outcome differ sharply. 738

The ovarian cycle consists of alternating follicular and luteal phases. 741

The follicular phase is characterized by development of maturing follicles. 741

The luteal phase is characterized by the presence of a corpus luteum. 744

The ovarian cycle is regulated by complex hormonal interactions. 744

Cyclic uterine changes are caused by hormonal changes during the ovarian cycle. 749

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Fluctuating estrogen and progesterone levels produce cyclical changes in cervical mucus. 751

Pubertal changes in females are similar to those in males. 752

Menopause is unique to females. 752

The oviduct is the site of fertilization. 752

The blastocyst implants in the endometrium by means of its trophoblastic enzymes. 755

The placenta is the organ of exchange between maternal and fetal blood. 757

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Hormones secreted by the placenta play a critical role in maintaining pregnancy. 761

Maternal body systems respond to the increased demands of gestation. 763

Changes during late gestation prepare for parturition. 763

Scientists are closing in on the factors that trigger the onset of parturition. 764

Parturition is accomplished by a positive-feedback cycle. 766

Lactation requires multiple hormonal inputs. 767
Breast-feeding is advantageous to both the infant and the mother. 770
The end is a new beginning. 770



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